Rethinking Ecology
SOFTWARE DESCRIPTION

Rethinking Ecology 4: 1–16 (2019)
doi: 10.3897/rethinkingecology.4.30890
http://rethinkingecology.pensoft.net

Twenty years and counting with SADIE: Spatial Analysis by Distance Indices software and review of its adoption and use

Linton Winder[1], Colin Alexander[2], Georgianne Griffiths[3], John Holland[4], Chris Woolley[5], Joe Perry[6]

1 *The Biological Husbandry Unit Future Farming Centre, Lincoln, New Zealand* **2** *Biomathematics and Statistics Scotland, The James Hutton Institute, Invergowrie, Scotland* **3** *College of Life and Environmental Sciences, University of Exeter, Penryn Campus, Treliever Road, Penryn, Cornwall, TR10 9FE, UK* **4** *Game and Wildlife Conservation Trust, Fordingbridge, Hants., UK* **5** *Evolutionary Studies Institute, University of the Witwatersrand, Johannesburg, Gauteng, South Africa* **6** *Oaklands Barn, Lug's Lane, Broome, Norfolk, NR35 2HT, UK*

Corresponding author: *Linton Winder* (lintonwinder@yahoo.co.uk)

Academic editor: *A.M.V. Fournier* | Received 29 October 2018 | Accepted 7 January 2019 | Published 21 January 2019

Citation: Winder L, Alexander C, Griffiths G, Holland J, Woolley C, Perry J (2019) Twenty years and counting with SADIE: Spatial Analysis by Distance Indices software and review of its adoption and use. Rethinking Ecology 4: 1–16. https://doi.org/10.3897/rethinkingecology.4.30890

Abstract

SADIE (Spatial Analysis by Distance Indices) is designed specifically to quantify patterns in spatially-referenced count-based data. It was developed for dealing with data that can be considered 'patchy'. Such distributions are commonly found, for example, in insect populations where discrete patches of individuals are often evident. The distributions of such populations have 'hard edges', with patches and gaps occurring spatially. In these cases variance of abundance does not vary smoothly, but discontinuously. In this paper we outline the use of SADIE and provide free access to the SADIE software suite, establishing Rethinking Ecology as its permanent home. Finally, we review the use of SADIE and demonstrate its use in a wide variety of sub-disciplines within the general field of ecology.

Keywords

SADIE, spatial analysis by distance indices, spatially-referenced, count

Copyright *Linton Winder et al.* This is an open access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Introduction

It is over twenty years since Joe Perry introduced and developed the SADIE (Spatial Analysis by Distance Indices) methodology to study spatial patterns in count-based data where locations are specified (Perry and Hewitt 1991; Perry 1995; Perry 1998). SADIE is designed specifically for analysing counts of individuals at known locations, and was developed for dealing with ecological data that can be considered 'patchy'. Such distributions are commonly found, for example, in insect populations where discrete patches of individuals are often evident. SADIE reflects this patchiness, recognised by ecologists, of populations in heterogeneous environments. Such populations have 'hard edges', with patches and gaps where variance of abundance does not vary smoothly, but discontinuously. Other approaches available to ecologists that allow the analysis of spatially-referenced data either assume a smooth surface for abundance with gradual change, so that populations may be viewed as contour maps of abundance (methods such as geostatistics, variograms, and Ripley's K), or allow the description of individuals (not counts) at specific locations through, for example, nearest-neighbour techniques or within area-based entities (such as maps of counties). We recommend that those reading this paper refer to the papers by Dungan et al. (2002) and Perry et al. (2002) that provide both a useful general introduction into techniques that may be used to explore spatial pattern in ecological datasets, and describe the use of SADIE within this context. The main message of Perry et al. (2002) is that one needs to tailor the choice of method to the available data type. The importance of tools to quantify and explore spatial pattern in ecological systems is recognised strongly in the wider literature (e.g. Campos-Herrera and Lacey 2018; Dungan et al. 2002; Fortin and Dale 2005; Madden et al. 2007; Perry et al. 2002; Samways and McGeogh 2010).

Traditionally, count-based spatial pattern has been explored using mean-variance relationships (e.g. Lloyd 1967; Taylor et al. 1978; Pacala and Hassell 1991). However, such approaches focus only on the frequency distribution of counts and not their location. Since they fail to retain important information with regards to the relative position in two dimensional space of each count, crucial information is lost (Figure 1a–c). This loss is important as it is known that the location of individuals in relation to one another mediates many ecological interactions (e.g. Hassell et al. 1991; Harwood et al. 2001).

Geographical Information Systems (GIS) approaches offer, in principle, tools to explore spatial solutions to this problem (Wegmann et al. 2016). However, GIS solutions are not well suited to ecological count-based data that often exhibit variances much greater than the mean (primarily due to the frequency of zero counts). GIS interpolation techniques, designed for smoothly changing gradients, do not deal well with discontinuities caused by aggregation of biological organisms into distinct populations with well-defined local boundaries, such as pollinators on flowerheads. Datasets of this type are common in ecology and particularly so in entomology where insect counts are often patchy. SADIE was developed in the entomology department of Rothamsted Research as a direct response to this problem. The method provides indices to detect and

measure clustering into 'patches' and 'gaps' for count-based data that is spatially referenced in two dimensions. The term 'cluster' is an important one in SADIE methodology and refers to a neighbourhood of either relatively large counts (a patch) or small counts (a gap). In addition, graphical displays termed 'red-blue' plots may be used to visualise the extent of clustering, and the location of patches and gaps. SADIE has been extended to provide a means to formally test the degree of association between two sets of spatially-referenced counts (Perry and Dixon 2002). This is particularly useful when, for example, it is desired to compare the spatial pattern of two species, of two dates or with abiotic data such as soil moisture (Holland et al. 2007).

A brief overview of SADIE methodology

In this section we provide an overview of the key elements of the SADIE system. Full details of methods and key papers that explore approaches to analysing spatially-referenced data are summarised in Table 1. In particular, the papers by Dungan et al. (2002) and Perry et al. (2002) provide a useful general introduction into analytical techniques that may be used to explore spatial pattern in ecological datasets. The SADIE approach has four key components: (i) an index of aggregation (I_a), quantifying the presence and degree of clustering; (ii) indices that quantify the presence of neighbourhoods of relatively high counts (V_i) or low counts (V_j), termed patches and gaps respectively; (iii) red-blue plots that provide a visual representation of the degree of clustering; and (iv) an association index (X), analogous to a correlation coefficient that represents the association or dissociation between two datasets which may also be mapped to create plum-green plots.

(i) **I_a, index of aggregation.** The method equates the degree of spatial pattern in a set of counts (each with an x,y coordinate) to the minimum effort that would be required to move to a completely regular arrangement with counts equal at each location. This is equated using the minimum distance, D, provided by a transportation algorithm from the linear programming literature (Kennington and Helgason 1980). A unique solution is provided based on notional flows of individuals from 'donor' sample units (with greater than average abundance) to 'receiver' units (with less than average abundance). From this solution, an aggregation index (I_a) is calculated that quantifies the degree of clustering independently of the numeric values of the counts (Figure 1a–c). This is generated by division of the observed value of D by the mean value generated from simulated randomisations of the counts among the locations. Values of $I_a = 1$ indicate randomly arranged counts, whilst $I_a > 1$ indicates aggregation of counts into clusters and $I_a < 1$ indicates regularity. Comparison of the observed value of D with the tails of the distribution of corresponding values from these simulations provides a randomisation test (Besag and Diggle 1977) of the null hypothesis that the observed counts are arranged randomly, with a probability level, P_a.

Table 1. Key papers that introduce SADIE analytical tools or provide an overview of general methods. A citation count using SCOPUS is also provided.

Paper	Scope	Citations
Perry 1995	The pattern of spatial distribution of *Dalbergia cearensis* saplings and adults were investigated with spatial analysis by distance indices, using the software Sadie Shell, version 8.0. The aggregation index (I_a) was used to explore spatial pattern.	205
Perry 1998	SADIE methodology is discussed in this paper and reviews the method's advantages over traditional approaches that measure only statistical variance heterogeneity. Two indices and associated tests are considered, one based on the total distance of the sample from a completely regular arrangement, the other from a completely crowded arrangement. A diagnostic plot is presented to aid interpretation. Methods are presented to estimate both 'typical' cluster size and inter-cluster distance.	225
Perry et al. 1999	This paper introduces a new index and four new graphical displays, termed 'red-blue' plots. The index may be used to detect clusters in the form of patches, comprising several nearby large counts, and in the form of gaps, comprising several nearby small counts. The methods facilitate a comprehensive definition of the size and dimension of a cluster.	266
Dungan et al. 2002	Case studies are used to explore the application of spatial methods. The influence of observational scale and the importance of carefully constructing both sampling design and analysis are reviewed. A set of considerations for sampling design to allow useful tests for specific scales of a phenomenon under study are provided.	432
Perry and Dixon 2002	A method to assess spatial association between two sets of count data is described. This uses a measure of local association for counts, based on comparison of SADIE clustering indexes of the two sets at each sample unit. The mean of the measure is represented by the simple correlation coefficient between the clustering indices of the two sets. Spatial association may be mapped for count data, and clusters of units with positive association or negative dissociation may be identified.	175
Perry et al. 2002	This paper provides guidance to ecologists with limited experience in spatial analysis to help in their choice of techniques. A case-study approach is used to compare analytical approaches. Guidance is provided through a taxonomy of data types, a discussion of the effects of sampling, and consideration of transformations that may be used to convert data. Key spatial analysis techniques developed in plant ecology, animal ecology, landscape ecology, geo-statistics and applied statistics are briefly reviewed. Users are encouraged to initially use simple visualisation techniques, followed by methods appropriate for the data type.	299

(ii) Patch and gap cluster indices (V_i and V_j). These indices are part of the 'red-blue' analysis tool and provide a means to measure the presence of spatial pattern by identifying neighbourhoods of consistently high counts (patches) or low counts (gaps) respectively. In the raw data, each location has its designated x,y coordinate and a corresponding count (c). SADIE assigns each location an index of clustering using the mean count m; either a positive ν_i index for patch units with $c_i>m$, or a negative ν_j index for gap units with $c_j<m$. These cluster indices are then used to calculate overall cluster indices V_i and V_j for patches and gaps, respectively, with associated significance values. The indices indicate whether the dataset is characterised by the presence of measurable patches, gaps, or both (Figure 1d).

(iii) Red-blue plots. Red-blue plots provide a visual representation of the degree of clustering (Figure 1d). Following their calculation of the values of ν_i and ν_j, cluster

20	0	20	0	5
0	20	0	20	3
20	3	0	20	5
6	20	8	3	9
0	5	20	0	20

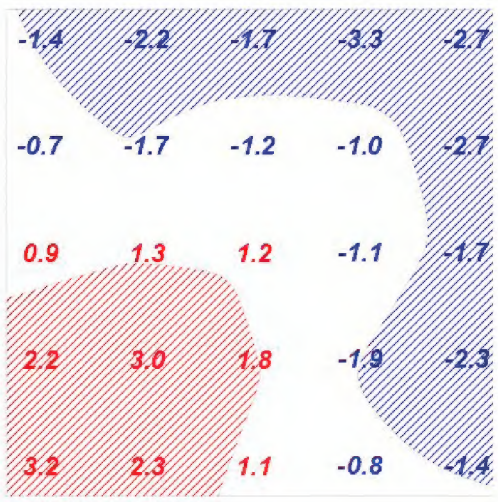
(a) I_a= 0.804, P = 0.96

20	0	20	3	3
20	5	0	9	0
5	20	0	20	0
3	8	5	20	20
6	0	20	0	20

(b) I_a= 0.945, P = 0.57

9	0	3	0	0
0	6	3	0	0
20	20	20	8	5
20	20	20	5	0
20	20	20	3	5

(c) I_a= 1.88, P < 0.002



(d)

Figure 1. In maps a-c, the same 25 counts, with mean, m = 9.08 and variance, s^2 = 75.9, are arranged in a 5×5 grid. The variance greatly exceeds the mean, so these counts come from a heterogeneous distribution more highly-skewed than the Poisson distribution. However, the frequency distribution of the counts (0^7, 3^3, 5^3, 6, 8, 9, 20^9) discards any information regarding the spatial arrangement of the counts. The arrangements clearly differ. In **a** the counts were deliberately arranged so that the larger counts are relatively far away from other large counts (and the smallest counts are far from other small counts), producing a distribution of the counts that is more regular than random. In **b** the counts were distributed completely randomly amongst the 25 cells of the grid. In **c** the larger counts are placed close to one another (as are the smaller counts), to yield a distribution that is highly clustered and spatially aggregated. The SADIE technique exposes these differences in spatial distribution. In **a** the SADIE index of aggregation I_a was less than unity (I_a = 0.80) indicating regularity, with corresponding probability level P = 0.96 indicating a significantly regular pattern. In **b** I_a is close to unity (I_a = 0.95, P = 0.57) indicating a randomly allocated pattern. In **c** I_a greatly exceeds unity (I_a = 1.88, P < 0.0002) indicating a significantly clustered pattern of patches and gaps. In **d** the value of the local index of clustering is shown for each of the 25 grid units of map **c** after SADIE analysis. Positive values, shown in red, indicate potential patches and negative values, shown in blue, indicate potential gaps; the larger the value, the greater is the evidence for clustering locally. Significant clustering into a patch in the lower left of the grid, and a gap on its opposite edge is shown where the units lie within the red (patch) or blue (gap) areas. In this example of a red-blue plot both patch (red, V_i=1.9, P<0.001) and gap (blue, V_j=-1.7, P<0.001) clusters are evident (Perry et al. 1999).

indices may be mapped, interpolated and contoured. Clusters are defined as areas enclosed by contour levels of +1.5 or –1.5; these indicate clustering (ν_i > 1.5 or ν_j < -1.5), half as great again as expected by chance. Whilst arbitrary, the average magnitude of the indices within contours bounded by these contour levels have

been found to approximate well to 95th centiles (centiles divide the ordered set of values into 100 parts) of their respective randomisation distributions. Once identified, clusters may be measured for size, shape, location and proximity to other clusters. Red-blue plots may be easily generated using software such as SURFER (Golden Software, current version 15).

(iv) **Association index X.** Two populations may be spatially positively associated, negatively dissociated, or not be associated at all. The SADIE suite of tools includes a measure of local spatial association, represented by the local index χ_k. This index is based on the similarity between the clustering indices of the two populations, measured locally at each location (Figure 2). Positive values of χ_k arise from coincidences of patches or of gaps in both populations; negative values from opposite cluster types. An overall index of spatial association (X) is calculated as the mean of local values, and is in fact equivalent to the simple correlation coefficient between the pairs of cluster indices. The significance of X may be tested by randomisations, after allowance for small-scale spatial autocorrelation from either population (Dutilleul 1993). It should be noted that measurable local association does not necessarily imply that larger scale spatial pattern is evident (a temporally stable but spatially random distribution would exhibit spatial association between consecutive sample dates). Plum-green plots provide an analogue of red-blue plots to visually assess areas of high association and/or dissociation.

Additionally, Xu and Madden (2005) proposed that a new index could be deployed following the SADIE approach. Li et al. (2012) introduced such an index that adjusts for the absolute location or the magnitude of the counts, and defines a new local clustering index.

Software availability

SADIE is available to users as a series of Windows-based programs that were developed by Kelvin Conrad and originally made available on his 'SADIE Re-heated website'. These programs have Help Files that provide both background on methods and instructions for use. Count-based data files (x, y, count) are required in simple text format. SADIE allows pairwise comparisons of distributions when association is being investigated. Other variables (e.g. continuous environmental variables) can also be incorporated into analyses, contingent on these data being spatially referenced. Continuous variables need to be integerized prior to analysis. In addition, Li et al. (2012) provide an R routine which calculates both the original SADIE indices and their alternative clustering index (https://www.rdocumentation.org/packages/epiphy/versions/0.3.4/topics/sadie) and the R package Epiphy (https://cran.r-project.org/web/packages/epiphy/vignettes/epiphy.html) includes SADIE analytical methods. The original SADIE program suite available for download with this paper includes:

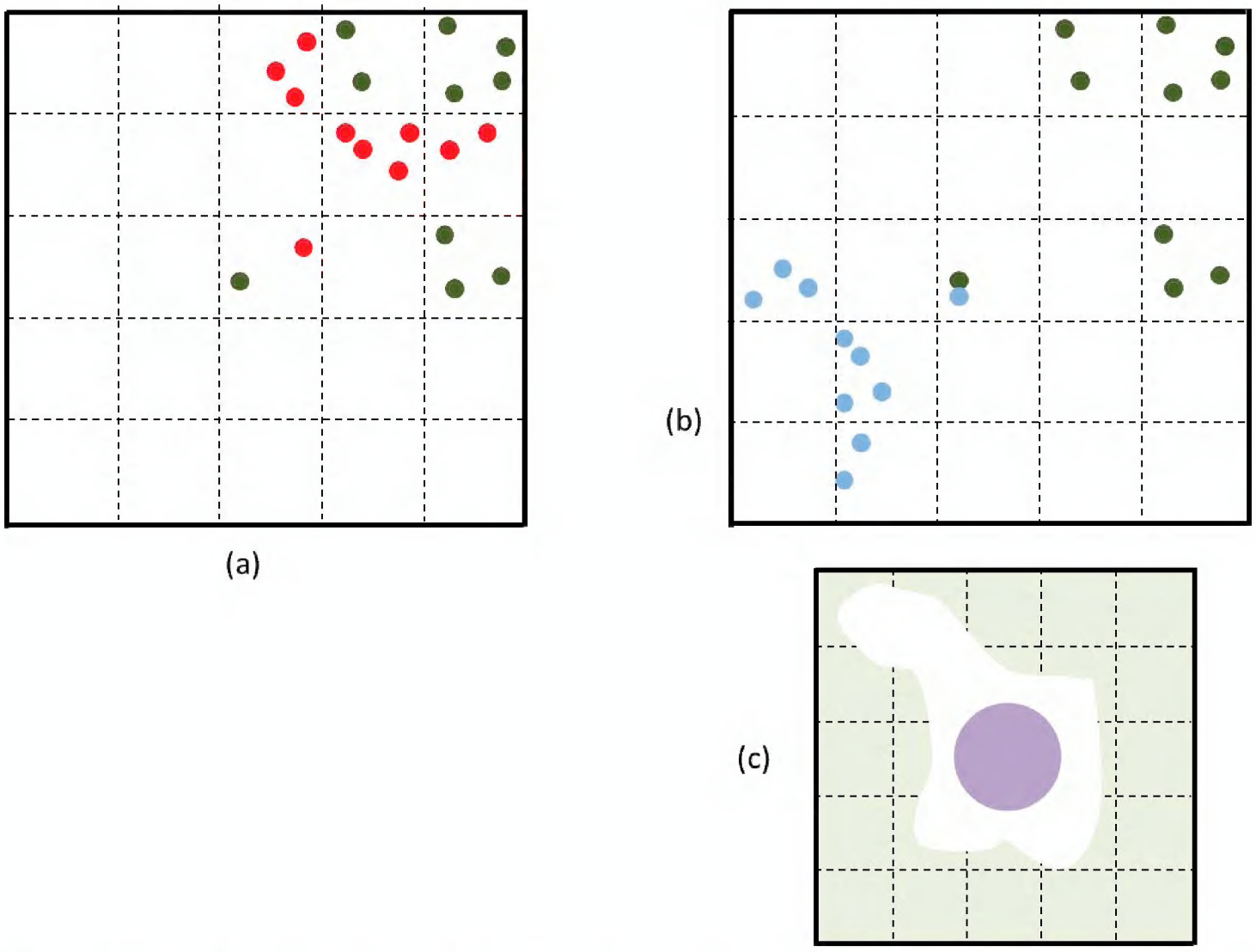


Figure 2. Spatial association and dissociation is illustrated by map **a** where there are ten red and ten green individuals, and map **b** where the ten green individuals are in exactly the same positions, and there are ten blue individuals. In fact, when viewed as single populations, the blues have a similar spatial pattern to the reds, their positions being merely a rotation and reflection of the reds. If counts were taken of the individuals in 25 cells using the dashed lines, then all three populations, red, green and blue, would each have identical frequency distributions: one count of 4, one of 3, one of 2, one of 1, and 21 zeroes. Furthermore, for both maps, only in the central cell do any of the non-zero counts coincide. For both the red-green counts and the blue-green counts, there are sixteen (0,0) pairs, one (2,0), one (0,2), one (3,0), one (0,3), one (4,0), one (0,4) and one (1,1) pair. The non-spatial correlation coefficient between the counts of the reds and greens, and between the blues and greens, is the relatively small value of -0.115, indicating no difference between the maps and neither strong similarity or dissimilarity. However, in **a** the ten red and the ten green individuals occur in similar areas and appear positively spatially associated and, by contrast, in **b** right-hand map, the ten green individuals occupy different areas and appear negatively spatially dissociated from the ten blue individuals. SADIE analysis gives the following values of I_a (with corresponding probability levels, P_a) for the green individuals: 1.45 (0.0079); for the reds: 1.18 (0.13); for the blues: 1.03 (0.36). Using the correlation between the clustering indices of each individual population, the SADIE index of association X (with corresponding probability level P) was, for the red and green populations in map (**a**): 0.578 (0.01); for the blue and green populations in map (**b**): -0.117 (0.66). The SADIE association index is capable of distinguishing the strong positive association in map (**a**) from the (albeit somewhat weaker) negative dissociation in map (**b**). In a similar fashion to red-blue plots, which give a visual representation of the degree and location of the clustering indices arranged into patches and gaps, SADIE association analysis allows the construction of plots that show areas of strong association and dissociation. For example the plot in map (**c**) is constructed from the association analysis of the clustering indices from the blue and red populations of map (**b**); it shows areas of significant positive association in plum and of dissociation in green.

- SADIEShell Version 2.0. Calculates the aggregation index I_a and red-blue indices V_i and V_j, with associated probabilities. Also generates the file "cluster.dat" which is required for association analysis;
- N_AShell Version 1.0. Calculates the association index X with associated probability for a pair of datasets;
- AssocBatchSetup01. Designed to perform all pairwise associations when there are more than two datasets; it operates on a list of SADIE spatial pattern results files. The resulting output comprises the association analysis results for the complete matrix (between any two sets) or a triangular matrix of comparisons, with each analysis held in a separate results folder.
- AssocExtractor060 Version 0.6. This program extracts the section of the file containing the local association indices. This is the equivalent of the cluster.dat file from SadieShell.
- ClusterShell Version 1.0. A program to measure characteristics of patch and gap clusters created by a SADIE red-blue analysis. Its purpose is to identify all patch and gap clusters by assigning each unit either to a cluster or to a non-clustered area. The program also identifies units that are on the boundaries of a grid, defines cluster centroids and examines the minimum distances between the cluster centroids and between the edges of clusters.
- Red-Blue Batch Runner Version 1.0. This program is specifically designed to perform a large set of spatial analyses. The resultant output is placed in the designated input folders and many analyses can be performed sequentially without additional user intervention. It has stringent requirements for data file names and folder storage. If only a few SADIE analyses are required, then SADIEShell is easier to use.
- Results Collector Version 0.61. This program extracts the section of the file containing the summary statistics and confidence intervals.

Review of studies using SADIE

We surveyed papers that included the phrase 'spatial analysis by distance indices' in the title or abstract using the SCOPUS database of peer-reviewed literature (www.scopus.com, accessed July 2018). This allowed us to identify studies that applied SADIE directly for analytical purposes, and provided a snapshot of the range of disciplines using the technique. In total, 130 papers were evaluated (Figure 3; Table 2), all of which were in the general field of ecology and spanned a wide range of sub-disciplines. Most studies (44) were entomological and were primarily concerned with pests or interactions between pests and their natural enemies. The fields of mycology and plant ecology were also strongly represented. Mycological studies (18) were primarily related to agricultural production, whilst plant ecology studies (18) focused more widely on natural ecosystems.

We also reviewed papers that were 'highly cited'; arbitrarily set at fifty SCOPUS citations excluding SADIE methodology papers (Table 3). The ten papers spanned

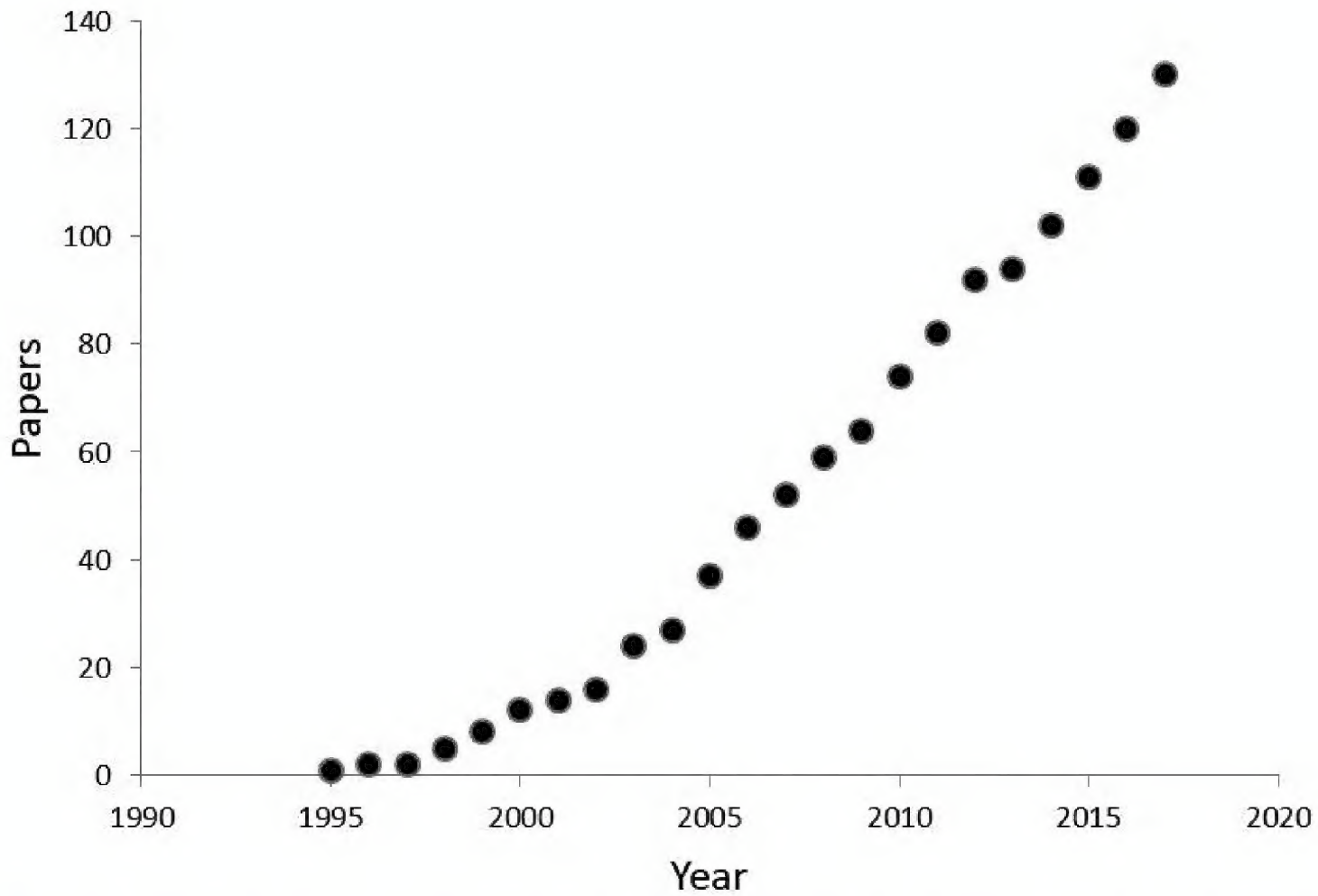


Figure 3. Cumulative number of papers published that use the phrase 'spatial analysis by distance indices' explicitly in the title or abstract. Data generated from searching the SCOPUS database for the period 1995–2017.

entomology (7), plant ecology (2) and mycology (1), demonstrating that the approach has been used successfully in a wide range of ecological disciplines. Examples of studies representing these three subject areas are:

- Maestre et al. (2003) investigated the role that soil surface properties play in semi-arid ecosystems. The study used both SADIE and principal components analysis to quantify patterns of seedling survival, identifying clearly defined areas of both high and low survival. Seedling survival was coupled primarily with the variables bare soil cover, sand content, and soil compaction. The results help inform restoration practices in semiarid ecosystems;
- Winder et al. (2001) studied the spatio-temporal dynamics of two aphid species (*Metopolophium dirhodum* and *Sitobion avenae*) and a generalist predator (*Pterostichus melanarius*). Using SADIE, ephemeral spatial pattern at the field scale was demonstrated. Additionally, a positive, lagged beetle response to this aphid pattern was observed whilst aphids displayed a negative, lagged response to beetle spatial pattern. A strong response by the beetle population to aphid patches was reported, and the spatially coupled dynamics were sufficient for the predator to have a negative effect on the intrinsic rate of increase of their prey;

Table 2. Snapshot of papers using the SADIE technique identified by interrogating the SCOPUS database using the search term 'spatial analysis by distance indices' within the abstract or title. Data presented as research field with short description and number of papers utilising the technique.

Research field	Description	Number of papers
Acarology	Mites as pests in agricultural systems	1
Agricultural Botany	Weed ecology	1
Animal Ecology	Ecology of animals in natural systems	5
Arachnology	Spiders as natural enemies in agricultural systems	2
Bacteriology	Pathology of bacterial diseases in agriculture	2
Biocontrol Plants	Biocontrol in natural (estuarine) ecosystems	1
Disease Ecology	Insect vectors of human diseases	2
Oligochaetology	Earthworm ecology in agricultural and natural systems	3
Entomology	Insect pests and their insect natural enemies	44
Fungal Ecology	Wood-decaying fungi in forest ecosystems	1
Marine Biology	Coral reef ecology	1
Methods	Extension of SADIE or allied methods	6
Mycology	Pathology of fungal diseases in agriculture	18
Landscape Ecology	Landscape-scale studies	4
Nematology	Nematode pests in agriculture	5
Oomycetes	Diseases in agricultural systems	2
Plant Ecology	General studies related to ecological theory or non-agricultural habitats	18
Pollution Ecology	Distribution of soil invertebrates	1
Limacology	Slugs as pests in agricultural systems	1
Stored Product Pests	Insect pests of stored products	2
Vertebrate Pests	Pests in agricultural systems	1
Virology	Pathology of viral diseases in agriculture	9

- Turechek and Madden (1999) studied the spatial pattern of strawberry leaf blight in perennial production systems. The study adopted an intensive sampling approach that evaluated infection at the level of leaflet, leaf, plant and field. Overall, results showed that the incidence of leaf blight was characterised mainly by small, loosely aggregated clusters of diseased leaflets.

Conclusions

The four key SADIE methods papers (Perry 1995; Perry 1998; Perry et al. 1999; Perry and Dixon 2002) have been cited 205, 225, 226 and 175 times on the SCOPUS database (www.scopus.com, accessed September 2018) respectively. At least 130 studies have used the approach to analyse spatially-referenced data (Table 2). Clearly, the method has therefore been adopted as a useful technique to approach the quantification of pattern in spatially-referenced count-based data. SADIE has allowed ecologists to utilise these intuitive and easily comprehensible indices and graphical outputs (red-blue and plum-green plots) in order to compare spatial distributions at either an instant in time, or along a time series. The software provides comprehensive tools to

Table 3. Highly cited papers from the SCOPUS database (arbitrarily set at more than 50) utilising SADIE as an analytical tool.

Authors	Title	Research Field	Cited
Winder et al. 2001	Modelling the dynamic spatio-temporal response of predators to transient prey patches in the field	Entomology	140
Maestre et al. 2003	Small-scale environmental heterogeneity and spatiotemporal dynamics of seedling establishment in a semiarid degraded ecosystem	Plant Ecology	139
Thomas et al. 2001	Aggregation and temporal stability of carabid beetle distributions in field and hedgerow habitats	Entomology	126
Thomas et al. 1998	Isolating the components of activity-density for the carabid beetle *Pterostichus melanarius* in farmland	Entomology	119
Maestre and Cortina 2002	Spatial patterns of surface soil properties and vegetation in a Mediterranean semi-arid steppe	Plant Ecology	110
Tillman et al. 2009	Spatiotemporal patterns and dispersal of stink bugs (Heteroptera: Pentatomidae) in peanut-cotton farmscapes	Entomology	74
Turechek and Madden 1999	Spatial pattern analysis of strawberry leaf blight in perennial production systems	Mycology	69
Ferguson et al. 2003	Spatial distribution of pest insects in oilseed rape: Implications for integrated pest management	Entomology	61
Winder et al. 2005	Predatory activity and spatial pattern: The response of generalist carabids to their aphid prey	Entomology	61
Winder et al. 1999	The spatial and temporal distribution of the grain aphid *Sitobion avenae* in winter wheat	Entomology	57

conduct SADIE analyses, but, we also encourage others to fully implement the approach under the R platform. It is hoped that the establishment of a permanent home for the SADIE software suite through Rethinking Ecology will encourage its use and further development.

Author contribution

Designed and wrote the manuscript: LW, CA, GG, JH, CW, JP. Prepared the figures: JP, LW.

Authors	Contribution	ACI
LW	0.20	1.250
CA	0.15	0.882
GG	0.15	0.882
JH	0.15	0.882
CW	0.15	0.882
JP	0.20	1.250

Acknowledgements

This paper is dedicated to the memory of our friend and colleague Dr Kelvin Conrad, whose love of science was an inspiration to us all. The UK's Biotechnology and Biological Sciences Research Council supported the development of SADIE.

References

Besag J, Diggle PJ (1977) Simple Monte Carlo tests for spatial pattern. Applied Statistics 26: 327–333. https://doi.org/10.2307/2346974

Campos-Herrera R, Lacey LA (2018) Methods for Studying the Ecology of Invertebrate Diseases and Pathogens. In: Hajek AE, Shapiro-Ilan DI (Eds) Ecology of Invertebrate Diseases. John Wiley and Sons, 680 pp. https://doi.org/10.1002/9781119256106

Dungan JL, Perry JN, Dale MRT, Citron-Pousty S, Fortin M-J, Jakomulska A, Miriti M, Rosenberg M (2002) A balanced view of scale in spatial statistical analysis. Ecography 25: 626–640. https://doi.org/10.1034/j.1600-0587.2002.250510.x

Dutilleul P (1993) Modifying the t test for assessing the correlation between two spatial processes. Biometrics 49: 305–314. https://doi.org/10.2307/2532625

Ferguson AW, Klukowski Z, Walczak B, Clark SJ, Mugglestone MA, Perry JN, Williams IH (2003) Spatial distribution of pest insects in oilseed rape: Implications for integrated pest management. Agriculture, Ecosystems and Environment 95: 509–521. https://doi.org/10.1016/S0167-8809(02)00200-1

Fortin MJ, Dale MRT (2005) Spatial Analysis: A Guide for Ecologists. Cambridge University Press, 454 pp. https://doi.org/10.1017/CBO9780511542039

Harwood JD, Sunderland KD, Symondson WOC (2001) Living where the food is: web location by linyphiid spiders in relation to prey availability in winter wheat. Journal of Applied Ecology 38: 88–99. https://doi.org/10.1046/j.1365-2664.2001.00572.x

Hassell MP, Comins H, May RM (1991) Spatial structure and chaos in insect population dynamics. Nature 353: 255–258. https://doi.org/10.1038/353255a0

Holland JM, Thomas CFG, Birkett T, Southway S (2007) Spatio-temporal distribution and emergence of beetles in arable fields in relation to soil moisture. Bulletin of Entomological Research 97: 89–100. https://doi.org/10.1017/S0007485307004804

Kennington JL, Helgason RV (1980) Algorithms for Network Programming. Wiley, New York, 308 pp. https://doi.org/10.1002/net.3230120107

Li B, Madden LV, Xu X (2012) Spatial analysis by distance indices: An alternative local clustering index for studying spatial patterns. Methods in Ecology and Evolution 3: 368–377. https://doi.org/10.1111/j.2041-210X.2011.00165.x

Lloyd M (1967) 'Mean crowding'. Journal of Animal Ecology 36: 1–30. https://doi.org/10.2307/3012

Madden LV, Hughes G, van den Bosch F (2007) The Study of Plant Disease Epidemics. American Phytopathological Society Press, 421 pp. https://doi.org/10.1094/9780890545058.001

Maestre FT, Cortina J (2002) Spatial patterns of surface soil properties and vegetation in a Mediterranean semi-arid steppe. Plant and Soil 241: 279–291. https://doi.org/10.1023/A:1016172308462

Maestre FT, Cortina J, Bautista S, Bellot J, Vallejo R (2003) Small-scale environmental heterogeneity and spatiotemporal dynamics of seedling establishment in a semiarid degraded ecosystem. Ecosystems 6: 630–643. https://doi.org/10.1007/s10021-002-0222-5

Pacala SW, Hassell MP (1991) The persistence of host-parasitoid associations in patchy environments. II. Evaluation of field data. American Naturalist 138: 584–605. https://doi.org/10.1086/285236

Perry JN (1995) Spatial analysis by distance indices. Journal of Animal Ecology 64: 303–314. https://doi.org/10.2307/5892

Perry JN (1998) Measures of spatial pattern for counts. Ecology: 1008–1017. https://doi.org/10.1890/0012-9658(1998)079[1008:MOSPFC]2.0.CO;2

Perry JN, Dixon P (2002) A new method to measure spatial association for ecological count data. Ecoscience 9: 133–141. https://doi.org/10.1080/11956860.2002.11682699

Perry JN, Hewitt M (1991) A new index of aggregation for animal counts. Biometrics 47: 1505–1518. https://doi.org/10.2307/2532402

Perry JN, Liebhold AM, Rosenberg MS, Dungan J, Miriti M, Jakomulska A and Citron-Pousty S (2002) Illustrations and guidelines for selecting statistical methods for quantifying spatial pattern in ecological data. Ecography 25: 578–600. https://doi.org/10.1034/j.1600-0587.2002.250507.x

Perry JN, Winder L, Holland, JM, Alston RD (1999) Red–blue plots for detecting clusters in count data. Ecology Letters 2: 106–113. https://doi.org/10.1046/j.1461-0248.1999.22057.x

Samways MJ, McGeoch MA, Tim R (2010) New Insect Conservation: A Handbook of Approaches and Methods. New Oxford University Press, 441 pp.

Taylor LR, Woiwod IP, Perry JN (1978) The densitydependence of spatial behaviour and the rarity of randomness. Journal of Animal Ecology 47: 383406. https://doi.org/10.2307/3790

Thomas CFG, Parkinson L, Griffiths GJK, Garcia AF, Marshall EJP (2001) Aggregation and temporal stability of carabid beetle distributions in field and hedgerow habitats. Journal of Applied Ecology 38: 100–116. https://doi.org/10.1046/j.1365-2664.2001.00574.x

Thomas CFG, Parkinson L, Marshall EJP (1998) Isolating the components of activity-density for the carabid beetle Pterostichus melanarius in farmland. Oecologia 116: 103–112. https://doi.org/10.1007/s004420050568

Tillman PG, Northfield TD, Mizell RF, Riddle TC (2009) Spatiotemporal patterns and dispersal of stink bugs (Heteroptera: Pentatomidae) in Peanut-Cotton Farmscapes. Environmental Entomology 38: 1038–1052. https://doi.org/10.1603/022.038.0411

Wegmann M, Leutner B, Dech S (2016) (Eds) Remote Sensing and GIS for Ecologists: Using Open Source Software. Pelagic Publishing, 324 pp. https://doi.org/10.14358/PERS.83.6.391

Winder L, Alexander CJ, Holland JM, Symondson WOC, Perry JN, Woolley C (2005) Predatory activity and spatial pattern: The response of generalist carabids to their

aphid prey. Journal of Animal Ecology 74: 443–454. https://doi.org/10.1111/j.1365-2656.2005.00939.x

Winder L, Alexander CJ, Holland JM, Woolley C, Perry JN (2001) Modelling the dynamic spatio-temporal response of predators to transient prey patches in the field. Ecology Letters 4: 568–576. https://doi.org/10.1046/j.1461-0248.2001.00269.x

Winder L, Perry JN, Holland JM (1999) The spatial and temporal distribution of the grain aphid Sitobion avenae in winter wheat. Entomologia Experimentalis et Applicata 93: 277–290. https://doi.org/10.1046/j.1570-7458.1999.00588.x

Xu X, Madden LV (2005) Interrelationships among SADIE indices for characterizing spatial patterns of organisms. Phytopathology 95: 874–883. https://doi.org/10.1094/PHYTO-95-0874

Supplementary material 1

Software 1

Authors: Joe Perry and Kelvin Conrad

Data type: software

Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.

Link: https://doi.org/10.3897/rethinkingecology.4.30890.suppl1

Supplementary material 2

Software 2

Authors: Joe Perry and Kelvin Conrad

Data type: software

Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.

Link: https://doi.org/10.3897/rethinkingecology.4.30890.suppl2

Supplementary material 3

Software 3
Authors: Joe Perry and Kelvin Conrad
Data type: software
Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.
Link: https://doi.org/10.3897/rethinkingecology.4.30890.suppl3

Supplementary material 4

Software 4
Authors: Joe Perry and Kelvin Conrad
Data type: software
Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.
Link: https://doi.org/10.3897/rethinkingecology.4.30890.suppl4

Supplementary material 5

Software 5
Authors: Joe Perry and Kelvin Conrad
Data type: software
Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.
Link: https://doi.org/10.3897/rethinkingecology.4.30890.suppl5

Supplementary material 6

Software 6

Authors: Joe Perry and Kelvin Conrad

Data type: software

Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.

Link: https://doi.org/10.3897/rethinkingecology.4.30890.suppl6

Supplementary material 7

Software 7

Authors: Joe Perry and Kelvin Conrad

Data type: software

Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.

Link: https://doi.org/10.3897/rethinkingecology.4.30890.suppl7